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AGRICULTURAL APPLICATIONS OF HEAT PUMPS IN ONTARIO

by

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ABSTRACT

This paper summarizes horticultural, livestock and poultry heat pump applications in Ontario.

Agricultural Applications of Heat Pumps in Canada

1.0 Introduction

The Ontario Ministry of Agriculture and Food (OMAF) is the branch within the provincial government that deals with the agricultural and food industry in Ontario. The responsibilities of the Ministry include regulating, conducting research and providing extension services to the farm community across Ontario. The Agricultural Energy Centre is a group within OMAF whose mandate is to demonstrate effective methods of increasing farm energy efficiency through the use of showcase demonstrations, financial assistance to share the cost of selected technology and a farm advisory service.

The OMAF Energy Centre has 8 field staff throughout Ontario managing projects as diverse as methane production for co-generation to evaluation of insulation materials as well as extension functions such as production of energy-oriented videotapes, factsheets, etc..

Ontario Hydro is the provincial electric utility with the responsibility of providing electrical power at cost to the people of Ontario. Ontario Hydro has installed generating capacity of 29,600 MW. Electrical power is sold wholesale to urban municipal utilities and is also retailed directly to rural customers, including 105,000 farm accounts. Ontario Hydro promotes the efficient use of energy, particularly electricity, to help customers get the best value for their money and to use existing generating facilities as effectively as possible while delaying the need to build new generating stations. Ontario Hydro is a winter-peaking utility with peak demand in the winter of 1986-87 reaching 20,600 MW.

Ontario Hydro has 14 agricultural marketing staff throughout the province. Their main functions are implementing marketing programs, providing practical information on farm energy use and promoting electricity sales in selected applications such as infra-red electric brooding.

It is assumed that most readers are familiar with heat pump technology and hence a description of heat pump principles of operation is not included in this paper. A selected list of heat pump terms is included at the end of the paper in the Appendix.

The major applications of heat pumps in Ontario agriculture are:

1. Horticulture - water-to-air for space heating of greenhouses
 - water-to-water for soil cooling and space heating of greenhouses
 - air-to-air for dehumidification of greenhouses
 - ground source for space heating and cooling of mushroom plants
2. Livestock Facilities - ground source for preheating incoming fresh air in broiler or livestock barns
 - recovery of heat from ventilation exhaust air in livestock barns to provide heat for the farm home
 - recovery of excess heat from within hog finishing barns to provide heat for the farm home
 - recovery of milk heat to preheat dairy washwater or water for calf feeding

2.0 System Descriptions

Design capacities and needs depend on climate and application. The Ontario climate varies considerably with summer design temperatures ranging from 27° C to 31° C. Winter design temperatures range from -15° C to -39° C. Most of the existing heat pump installations are in the southwestern and central areas of the province because these are the areas with most of the farms. The design temperatures in these areas of the province are approximately -20° C in winter and 30° C in summer. Ground source heat pumps are also being used in the northern areas of the province in residential and commercial applications.

The mention of manufacturers' trade names is for the purpose of specific equipment description and does not indicate an endorsement of that equipment or discrimination of similar equipment by the authors, the Ontario Ministry of Agriculture and Food or Ontario Hydro.

All prices listed are in Canadian dollars. The approximate exchange rate at the time this paper was prepared was \$1 CAN = \$0.75 US.

2.1 Greenhouses

Mastronardi Greenhouse - Water-to-Air Heat Pumps for Space Heating

Three 42kW (12 Ton) water source heat pumps supply space heating to a 9m x 71m polyethylene-covered greenhouse. Two wells are used in this system; one for supply and one for discharge. Water temperature from the supply well remained very constant over 3 years at 15° C plus/minus 1 C°. Each heat pump needs 2 L/s of water when they are running. The 3 heat pumps are sequenced such that one heat pump runs constantly whenever heat is required and the other units come on as needed. Heat is distributed via polytubes overhead in the greenhouse. Refer to Figure 1.

Measured Seasonal Coefficient of Performance (COP) was 2.5. Heating cost savings compared to a natural gas-fired central boiler were 40%. The 3 heat pumps supply 50% of the heat demand for an outside design temperature of -15° C.

A realistic payback was unachievable with this system design. A better payback can be achieved by placing one unit in each greenhouse bay to supply base load heating requirements and allowing heat pumps to run continuously whenever heat is needed.

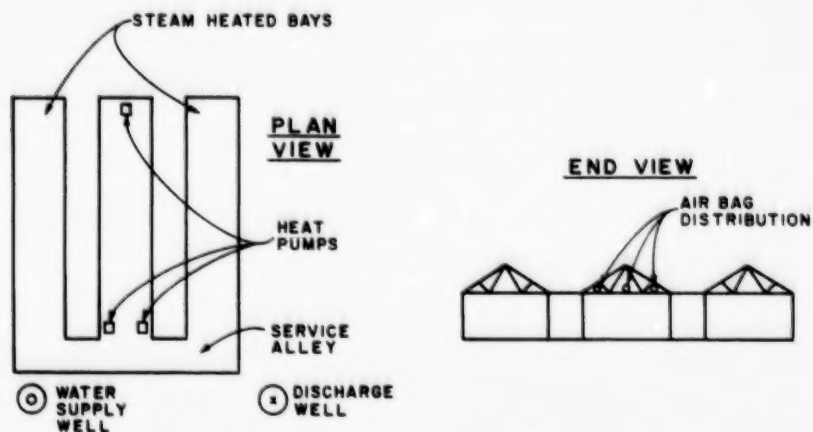


FIGURE 1: SCHEMATIC OF MASTRONARDI WATER-TO-AIR HEAT PUMP SYSTEM

Lakeshore Flowers Greenhouse - Water-to-Water Heat Pumps for Soil Cooling & Air Heating

Three 17.5kw (5 Ton) water source heat pumps cool water that is pumped through 25 cm diameter polyethylene plastic pipes laid 150 mm deep in the ground adjacent to rows of Alstroemerias. The soil must be maintained in the range of 12°-15° C in order for these plants to flower. See Figure 2.

The heat pumps provide 100% of cooling demand and a portion of the heating requirements for an outside design temperature of -15° C. When used in heating mode, the heat pumps heat water that is pumped to fan-coil units which distribute the heat in the greenhouse. The heat pumps are not used to heat the soil as soil heating is not needed to maintain the required soil temperature. Supplementary space heating is provided by a natural-gas fired central boiler. The two greenhouses each are 16 m x 61 m. The heat pumps are controlled by programmable thermostats now tied into a greenhouse environmental computer. Measured Seasonal Coefficient of Performance (COP) is not available.

Without soil cooling, only 1 crop of flowers would be harvested by timing the expected flowering with the rise in soil temperature during the spring. Soil cooling allows the grower to control the conditions such that the flowers may be harvested throughout the year. The timing of the flowering of the plants can be controlled to coincide with the periods of greatest demand and highest price. Payback calculations are not possible because the operation using soil cooling cannot be compared to what could be done without soil cooling. The base load heating provided by the heat pumps is an added benefit.

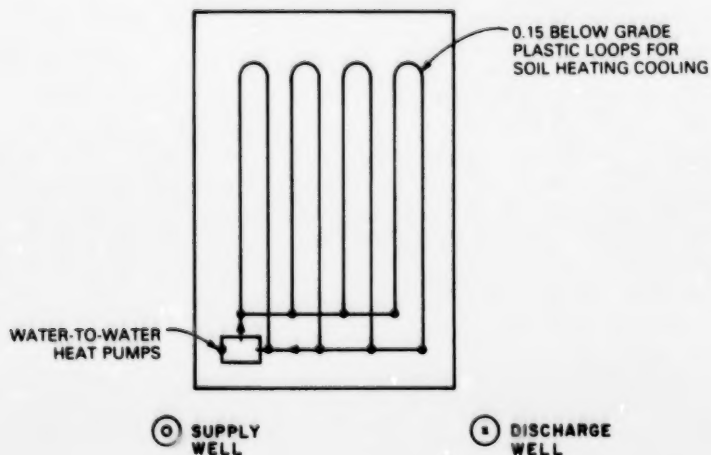


FIGURE 2: SCHEMATIC OF WATER-TO-WATER HEAT PUMPS FOR SOIL COOLING

Oak Farms Greenhouse - Dehumidification

Two 5 Ton Dry-O-Tron dehumidifiers are being used in a rose greenhouse to maintain acceptable humidity levels during the winter. Dehumidified air is distributed in the greenhouse by poly airtubes. The use of the dehumidifiers minimizes the amount of cold outside air introduced during the winter, thus reducing energy used to heat infiltration air. The latent heat of condensation contributes to the space heating. Refer to Figure 3. Monitoring is now completed but results are not yet available.

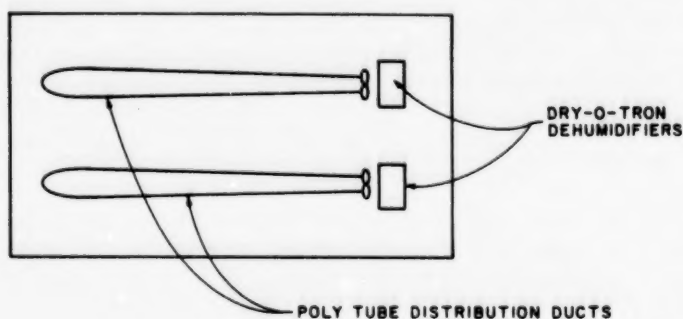


FIGURE 3: SCHEMATIC OF GREENHOUSE DEHUMIDIFICATION SYSTEM

2.2 Peeters Mushroom Plant - Ground Source Heat Pumps for Space Heating and Cooling

Five 17.5kW (5 Ton) ground source water-to-water heat pumps are used to provide the total cooling and partial heating requirements for a mushroom plant with 6 growth rooms, each with a bed area of 370 square meters. The ground loop consists of 2400m of 38mm diameter polyethylene pipe buried 2300mm deep in an adjacent field. The ground loop piping is almost 1000mm deeper than conventional residential ground loops to ensure the loop would be in saturated soil, especially during times of heavy cooling load when heat is rejected to the ground. The ground piping is laid out in eight equal length loops, each 350 meters long. Refer to Figure 4.

Three heat pumps are used in the heating mode. All five heat pumps are used in the cooling mode. They are staged to provide better control and reduce energy wastage due to overloading or underloading. A natural gas-fired boiler is still needed to provide steam for compost cookout and some supplemental winter heating.

Tests were carried out in which either the heat pumps or the gas boiler was used exclusively for heating for a 24 hour period. It was found that the average heating cost reduction by using the heat pumps was 56% based on an electricity price of \$0.05/kWh and a natural gas price of \$0.19 per cubic meter.

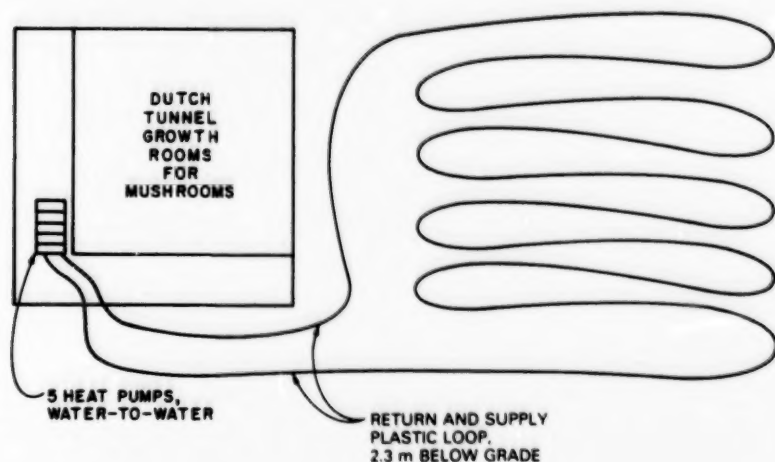


FIGURE 4: SCHEMATIC OF PEETERS WATER-TO-WATER HEAT PUMP SYSTEM

2.3 Livestock Facilities

Exhaust Air Source Heat Pumps

Dairy Barn - Bauman

This custom built system is installed in a 40 milking cow operation. An evaporator coil is installed on the outlet side of the winter exhaust fan. Recovered heat is piped underground using copper tubing to the farm home basement. The distance from the barn to the house is about 50 m. The suction line is 35 mm diameter copper piping and the liquid return line is 13 mm diameter copper piping. Distances greater than this will require larger lines and significantly affect system cost. A 17.5kW (5 ton) compressor is located adjacent to the existing Olsen Duo-matic wood/oil furnace. The condenser coil is located in the return air plenum. Refer to Figure 5.

Originally, a 5 fin/cm (12 fin/in) copper coil with serrated aluminum fins was installed. This type of coil tends to clog quickly with dirt causing frost build-up and decreased efficiency.

A new evaporator coil system was constructed using 2.3 fin/cm (6 fin/inch) and steel tubing and fins. There are five coils in parallel.

This system has a steady-state COP up to 2.5. System cost was \$6000. and payback was less than 5 years. Less than 10% of heating requirements were supplied by the backup oil furnace.

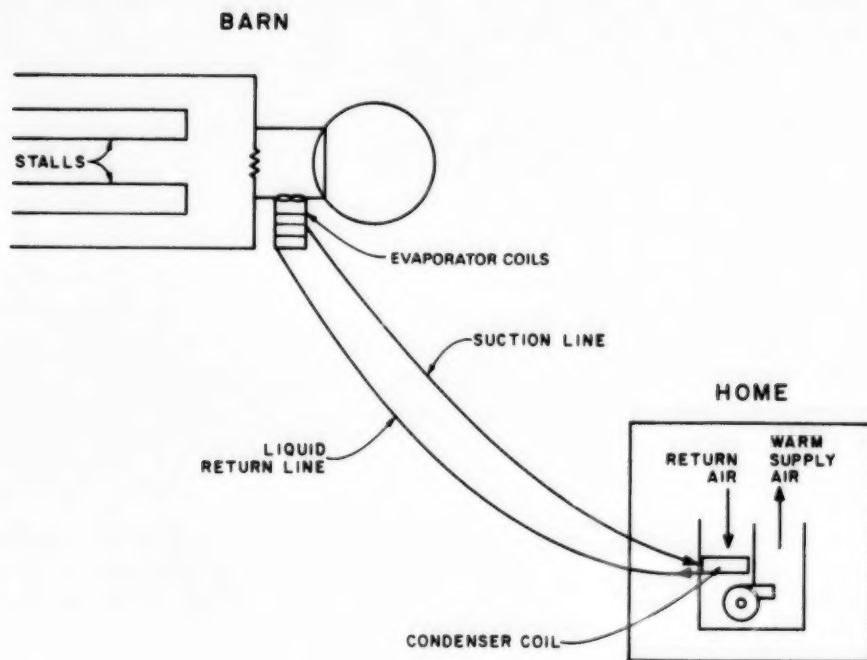


**FIGURE 5 : SCHEMATIC OF BAUMAN EXHAUST AIR
SOURCE AIR-TO-AIR HEAT PUMP**

Dairy Barn - Grieve

This Enertran dual heat pump system recovers dairy barn exhaust air heat from 55 milking cows but with a twist from the Bauman system. It utilizes an 11kW air-to-water heat pump in the barn for heat recovery and a 16kW water-to-air heat pump in the home for home heating. A 2000 litre storage tank in the basement acts as heat storage, ensuring a heat supply during extreme cold and also while cattle are out of the barn each morning. The distance from barn to house is about 50 m. The water supply and return PVC pipes are buried about 1.5 m below grade and are uninsulated. Some heat is lost to the ground in very cold weather. Refer to Figure 6.

Unfortunately, the system COP was as low as 1.2 during the 1985-86 test period. This low COP is due to the use of two heat pumps and some barn evaporator coil plugging from dirt build-up.

To improve system efficiency, a new barn exhaust air evaporator coil, similiar to the one used in the Bauman heat pump will be installed.

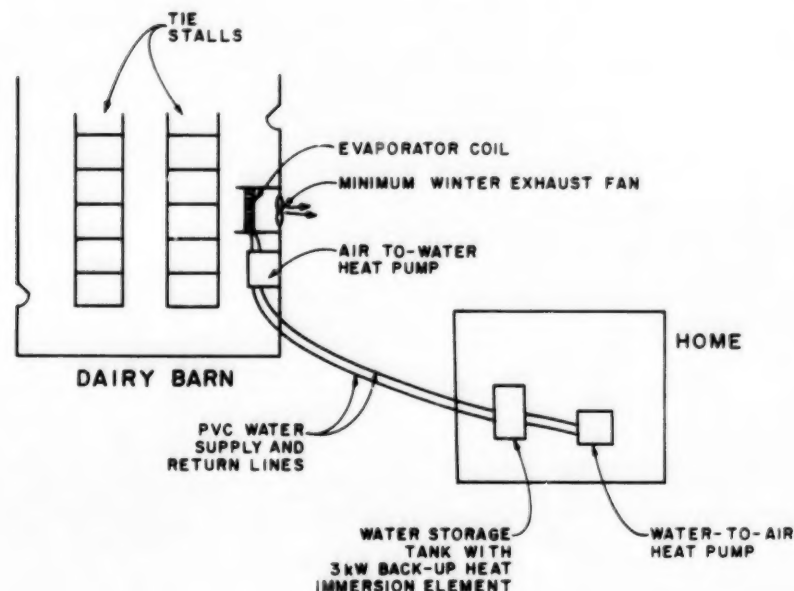


FIGURE 6: SCHEMATIC OF GRIEVE DUAL HEAT PUMP SYSTEM

Hog Barn - Smith

This system uses a water-to-air heat pump. PVC tubing is formed in an open coil about 1 m in diameter. The coiled tubing is suspended in a hog finishing barn over the dunging area which is adjacent to the wall with all the exhaust fans. Water is continually pumped through the coils (about 450 m long) and then underground to the home, about 50 m distant. The PVC tubing, buried 1.5 m below grade, is uninsulated and, like the Grieve heat pump, loses some efficiency during very cold weather. A 15kW heat pump in the basement recovers heat which is used to heat the home in winter and an outdoor pool in the summer. Refer to Figure 7. The owner plans to extend the heat pump use by supplementing domestic hot water heating.

Estimated system COP for the 1986-87 heating season was 2.5. Installed cost was \$6000. Oil consumption has been reduced to less than 5% of past use and payback is estimated at less than 4 years. Any wood in contact with the PVC piping should be a type of wood that will resist rot under almost continuous wet conditions due to condensation on the piping.

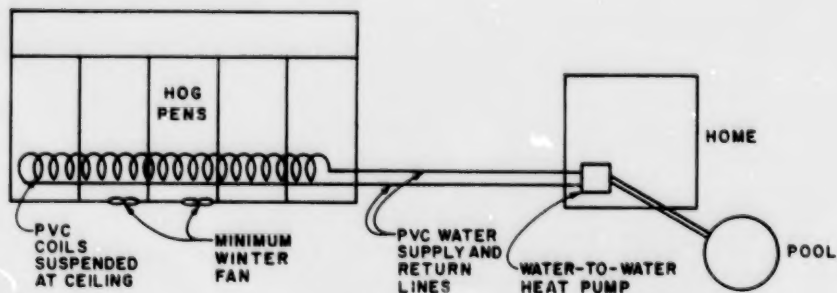


FIGURE 7: SCHEMATIC OF SMITH EXHAUST AIR SOURCE ,
WATER-TO-WATER HEAT PUMP

Hog Barn - Van Clief

This was the first heat pump system used in an Ontario livestock facility. An off-the-shelf residential air-to-air heat pump was installed in a shelter attached to the hog finishing barn. Exhaust air passed through the evaporator coil and recovered heat for multiple farrowing and weaning rooms. See Figure 8.

This system was abandoned after 3 years of operation. The condensing coil solder joints began to leak due to corrosion. Surprisingly, the evaporator coil did not have any leaks. This was because it was always quite cool and was continually coated with condensed water, effectively shielding it from the corrosive gases.

This type of 'off-the-shelf' system is not recommended for livestock applications due to the corrosive nature of the air and high dust levels.

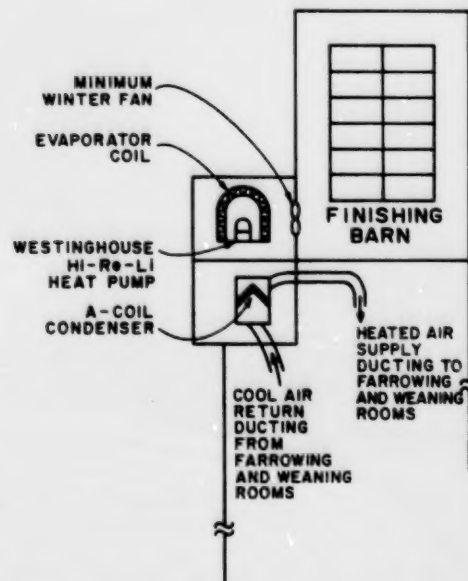


FIGURE 8: SCHEMATIC OF VAN CLIEF
AIR-TO-AIR HEAT PUMP SYSTEM

Poultry Barn - Fisher

This system uses three ground source loops to provide heat for a three floor poultry barn (12,500 birds/floor). Each loop, 500 meters long, supplies a Cantherm Duo 500 11.5 kw output water-to-water heat pump. The units are sequenced to operate on demand as the heating requirements rise. All three heat pumps provide heated water to a central storage tank. This heated water is continually pumped to each floor through a hot water radiator. A thermostatically operated fan blows fresh outside air across these hot water radiators as required. This heated fresh air is distributed throughout the space by ducts and circulation fans. See Figure 9.

Supplemental heat is provided by radiant tube propane heaters. In warmer weather and later stages of winter crops, 100% of the heating requirements is provided by the heat pumps. Cold weather combined with young chicks requires substantial propane use, up to 50% of the total peak demand.

The installed cost was \$38,000. However it is expected that future installations would be in the range of \$22,000 to \$25,000.

System performance is still being monitored.

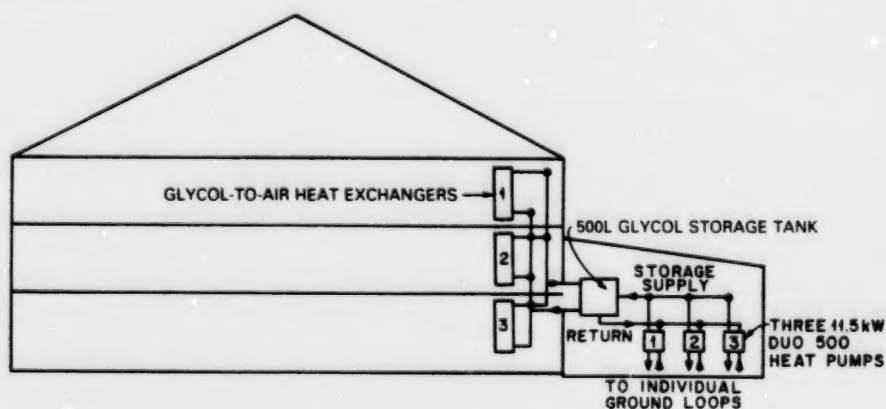


FIGURE 9: SCHEMATIC OF FISHER GROUND SOURCE HEAT PUMP SYSTEM FOR POULTRY BARN HEATING

Summary

Horticultural Applications

Ground and water source heat pumps provide efficient base load heating for Ontario greenhouses and mushroom plants. Attempting to meet peak heating demand requirements will result in equipment cycling plus, during warmer weather, equipment sitting idle.

Heat pumps are competitive even with Ontario's energy costs of \$0.19 - \$0.22 per cubic meter for natural gas, \$0.20 per litre for propane, \$0.055/kWh for electricity and \$0.30 per litre for oil.

There are now up to 20 water source heat pump systems in greenhouses and mushroom plants. It is expected there will be many more as the system gains acceptance in Ontario's horticultural industry.

Table 1 lists a comparison of horticultural heat pump applications.

Livestock and Poultry

There are many sources and sinks for heat around livestock and poultry farms. The major sources are:

1. Ground
2. Well water
3. Exhaust air
4. Bulk milk coolers

The major uses are:

1. Hot water (domestic and barn)
2. Barn space heating
3. Home and work shop space heating
4. Pool heating

Heat recovery remains the more expensive and certainly most troublesome aspect of these systems, except for well water systems. Exhaust air from livestock and poultry barns is both corrosive and dirty. Using extended runs (500+ meters per 11.5kW of heat output) of PVC tubing is the simplest to install and maintain. Depending on the application, it may also be the most expensive.

The use of heat pumps in livestock facilities is not currently accepted as well as in horticultural applications. This is partly because of the fact that energy costs in livestock operations usually form a lower percentage of operating costs than in horticultural operations. The use of heat pumps in livestock and poultry operations also has additional complications compared to horticultural applications. However, different methods can be employed for individual applications to yield satisfactory results and reasonable paybacks.

Table 2 lists a comparison of livestock and poultry heat pump applications.

Conclusions

Heat pumps in Ontario agriculture are well established. Current systems are varied and particularly for livestock applications, some custom design work is required.

Both Ontario Hydro and the Ontario Ministry of Agriculture and Food through the Agricultural Energy Centre are continuing with programs to promote use and research new ways to effectively use heat pumps.

Acknowledgements

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TABLE 1

Comparison of Heat Pump Systems in Horticulture

<u>System</u>	<u>Source</u>	<u>Sink</u>	<u>Cost</u>	<u>COP</u>	<u>Comments</u>
MASTRONARDI Greenhouse; Water-to-Air Space Heating	Well	Greenhouse	\$45,200.	2.5	Heating cost savings of 40% compared to natural gas. No payback due to capital cost of heat pump capacity needed to meet 50% of heating demand.
LAKESHORE FLOWERS Soil Cooling	Greenhouse Soil	Well Water	\$26,400	N/A	System works well. Maintaining soil temperature between 12°-15° C
OAK FARMS Greenhouse; Dehumidifica- tion	Latent Heat of Condensation	Greenhouse			Use of dehumidifiers reduces amount of cold fresh air brought in and associated heating costs. Latent heat of condensation contributes to space heating.
PEETERS Mushroom Plant Cooling & Heating	Ground Loop	Mushroom Plant			Ground loop deeply buried to reach saturated soil needed for heavy cooling loads. Heating cost reduction of 56% compared to natural gas.

TABLE 2

Comparison of Heat Pump Systems
in Livestock and Poultry Facilities

<u>System</u>	<u>Source</u>	<u>Sink</u>	<u>Cost</u>	<u>COP</u>	<u>Comments</u>
BAUMAN Dairy; Air-to-Air	dairy barn exhaust air	home htg	\$6000.	2.5	Evaporator coil requires maintenance. Fin spacing should be at least 2.5 fins/cm.
GRIEVE Dairy; Air-to-Water and Water-to-Air	dairy barn exhaust air	home htg	\$9000.	1.2	Low COP, not recommended. System also provides air- conditioning.
VANCLIEF Hog; Air-to-Air	finishing hog barn exhaust air	farrowing and weaning rooms	\$12000.	2.0	Component failure due to use of unprotected 'off- the-shelf' components. Not recommended.
SMITH Hog; Air-to-Air	finishing hog barn exhaust air	home heating	\$6000	2.5	Excellent system, low maintenance. Care must be taken during cold weather not to reduce temperature in finishing barn below lower critical temperature.
FISHER Broilers; Ground-to-Water	Ground	Poultry	\$38,000	2.5	Three heat pumps used to supply hot water to central storage tank. Hot water is pumped to each of 3 floors where a fan passes incoming fresh air through a heat exchanger.

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APPENDIX

CONVERSIONS AND TERMINOLOGY

1. Common Conversions

1 horsepower	=	2545 Btu/hour
1 horsepower	=	745.7 Watts
1 joule	=	1 N m
Kelvin	=	($^{\circ}\text{C} + 273.15$)
Celsius	=	($^{\circ}\text{F} - 32$)/1.8
1 kilowatt	=	3600 kilojoules
1 kilowatt-hour	=	3413 Btu
1 therm	=	10^5 Btu
1 ton (refrigerant)	=	12002.84 Btu/hour
1 ton (refrigerant)	=	3516.8 Watts
1 Watt	=	1 joule/second
1 Watt	=	3.413 Btu/hour

2. Glossary of Definitions and Terms

Accumulator - A storage vessel for liquid refrigerant that prevents the liquid from entering the compressor.

Air-Source Heat Pump - A heat pump that uses an air-to-refrigerant heat exchanger to extract heat from an air source.

Closed Fluid System - In a ground coupled heat pump system, or a pressurized heat exchange system in which heat transfer fluids are not exposed to atmospheric pressure.

Coefficient of Performance (COP) - Ratio (in consistent units) of heating output of heat pump to energy input under specific operating conditions.

Compressor - The main component of a heat pump system. It increases the pressure on the refrigerant, which in turn increases the refrigerant temperature. The compressor also moves the fluid through the system.

Condensation - The process by which vapor is changed to a liquid, upon the release of heat.

Condenser - A heat exchanger in which the refrigerant, after having been compressed to a suitable pressure, is condensed by rejection of heat to an external cooling medium.

Degree Days (DD) - For any heating day there are as many degree days as there are degrees difference between 18°C (65°F) and the mean temperature for the day when the latter is below 18°C (65°F). The mean temperature is the mid-point between the highest and lowest temperature recorded. Degree Days is a measure to correlate the outside temperature with the energy required for heating based on the assumption that heating is required when the average daily temperature is less than 19°C . Thus, one heating Degree Day results from an average of 17°C for 24 hours. The Degree Days are accumulated to provide a means of comparing the influence of weather on energy usage over a period of time.

Design Temperature - The "design temperature" for a given month is usually taken to be the temperature value at or below which only 2 1/2% of recorded January hourly outdoor temperatures occurred during the years at record for that locality. Design temperature is the outdoor air temperature that is exceeded 97.5% of the time during the winter.

Energy - The capacity for doing work; taking a number of forms that may be transformed from one into another, such as thermal (heat), mechanical (work), electrical, and chemical; in customary units, measured in kilowatt-hours (kW.h) or megajoules (MJ).

Evaporation - The process of changing a liquid to a vapor; requires the addition of heat to the liquid.

Evaporator - A heat exchanger in which the liquid refrigerant, is evaporated by absorption of heat from the medium to be cooled.

Expansion Device - A device that reduces the pressure of liquid refrigerant entering the evaporator and meters or regulates the flow of refrigerant so that it can properly absorb heat.

Gas, Hot - The vapor discharged from the compressor in a vapor compression cycle - the gas is "hot" as compared to the suction gas due to the addition of energy in the form of work of compression.

Gas, Suction - The refrigerant vapor on the suction side of a compressor in a vapor compression cycle; the evaporator coil discharge gas.

Ground Coupled System - A closed loop, ground source heat pump system which extracts heat from a ground source through a water/antifreeze solution circulated in pipes buried in the earth either horizontally or vertically.

Heat Exchanger - A device specifically designed to transfer heat between two physically separated fluids.

Heat Pump - An electrically operated mechanical device capable of supplying both heating and air conditioning functions. It does this by extracting heat from a heat source and moving to a heat sink, rather than generating heat. Heat pumps are either water-source or air-source.

Heat Sink - The medium which receives heat from a heat pump.

Heat Source - The medium from which heat is extracted by a heat pump.

Infiltration - The process by which outdoor air leaks into a building by natural forces through cracks around doors and windows, etc.

Kilowatt (kW) (1000 W) Means a heat flow equal to 3,413 Btu/hr.

Kilowatt Hour (kWh) - 1 kWh (1000 W/hour) - Means an amount of heat equal to 3,413 Btu.

Latent Heat - The heat associated with a change in state.

Open - Fluid System - In a ground-coupled system, a heat exchanger system in which the transfer fluid is exposed to atmospheric pressure.

Refrigerant - A fluid of extremely low boiling point used to transfer heat between a heat source and heat sink by changing states from a liquid to a vapour, and back.

Reversing Valve - A two-position refrigerant valve that changes the mode of operation of heat pump from heating to cooling to heating, by changing the refrigerant's direction of flow.

Sensible Heat - Heat associated with a change in temperature as opposed to the heat associated with a change in state.

Suction Line - Tube or pipe that carries refrigerant from the evaporator to the compressor.

Supplementary Heat - Heat from a source other than a heat pump (electrical resistance, fossil fuel furnace, solar heated water coil, etc.) used to make up the difference between the heat pump output and the building heat loss below the thermal balance point of the heat pump and/or to supply all of the required heat below the cut-off temperature of the heat pump.

Ton of Refrigeration - A useful refrigerating effect equal to approximately 12,000 Btu per hour; 1 ton = 3.517 kW of refrigeration (see conversions on page 1 - Section 11)

Water-Source Heat Pump - A heat pump that uses a water-to-refrigerant heat exchanger to extract heat from the heat source.